CONTRACT NO. 95-312
FINAL REPORT
AUGUST 1998

Allergens in Paved Road Dust and Airborne Particles

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
AIR RESOURCES BOARD
Research Division

ALLERGENS IN PAVED ROAD DUST AND AIRBORNE PARTICLES

Final Report
Contract No. 95-312

Prepared for:

California Air Resources Board
Research Division
2020 L Street
Sacramento, CA 95814

Prepared by:

Ann G. Miguel, Glen R. Cass, M. Michael Glovsky and Jay Weiss
Environmental Engineering Science Department
California Institute of Technology
Pasadena, California 91125

August 1998

DISCLAIMER

The statements and conclusions in this Report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their sources, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

This report was prepared as a result of work sponsored in part by the South Coast Air Quality Management District (District). The opinions, findings, conclusions and recommendations are those of the authors and do not necessarily represent the views of the District. The District, its officers, employees, contractors, and subcontractors make no warranty, expressed or implied, and assume no legal liability for the information of this report. The District has not approved or disapproved this report, nor has the District passed upon the accuracy of the information contained herein.

Table of Contents

Acknowledgments

We would like to thank first and foremost Christos Christoforou, a fellow colleague at Caltech, for the long hours spent on the road helping with the collection of paved road dust samples. Soloman Teffera, Steve Barbosa, Alicia Diaz and George Diaz of the SCAQMD were most helpful in the acquisition and organization of the airborne particulate samples and associated data. The advice and assistance of several Caltech colleagues is gratefully acknowledged. We would like to thank Mike Kleeman, Jamie Schauer and Paul Mayo for help with the paved road dust size-fractionation experiments and Lynn Salmon for the inorganic ion analyses. Peter Green and Tony Miguel provided assistance with the ICP-MS analysis. The staff at the Desert Research Institute performed the XRF analyses and Bob Cary at Sunset Laboratories carried out the EC/OC analysis. We thank Zeb Dyer at the Santa Barbara Medical Foundation Clinic for examination of the paved road dust samples by optical microscopy to confirm the presence of molds and pollen grains. We also thank Manny Odontis and Ercan Unver of Diagnostic Products Company for advice and support during the blotting analysis and Robert Gunsalus at UCLA for arranging for the use of the scanning densitometer.

List of Figures

List of Tables

Abstract

The purpose of the research reported here is to quantify the allergen content of paved road dust and to estimate the magnitude of the road dust contribution to airborne allergen concentrations. Paved road dust present on the surface of streets in Southern California consists of a complex mixture of soil dust, deposited motor vehicle exhaust particles, tire dust, brake lining wear dust, plant fragments and other biological materials. The research presented here shows that allergens from at least 20 different source materials are found in the paved road dust. These include pollens and pollen fragments, animal dander and molds. Natural rubber latex allergens were not detected in the present work but have been measured in previous studies. When paved road dust is resuspended into the atmosphere by passing vehicle traffic, allergen concentrations in the air are increased above the levels that would prevail without the vehicle traffic. Using immunological assays which measure the proteins extracted from environmental samples that bind to antibodies present in the blood serum of allergenic patients, it is possible to measure the allergen concentrations present in paved road dust and in airborne particle samples. Results show that 5% to 13% of the allergenicity of atmospheric total suspended particulate matter samples at Long Beach and Rubidoux, CA, is attributable to paved road dust emissions. In an industrial area of urban central Los Angeles where there is less proximity to vegetation and domestic activities, the paved road dust contribution to airborne allergen concentrations is lower, accounting for approximately 0.5% of the total allergenic activity of the atmospheric particle samples.

Executive Summary

Paved road dust reentrained into the atmosphere by passing vehicle traffic is one of the largest contributors to particulate matter emissions in urban areas. The paved road dust deposits present on the highway surface consist of a complex mixture of soil dust, deposited motor vehicle exhaust particles, tire dust particles, brake lining wear particles and plant debris fragments. Among the biological materials within the road dust mixture there exist pollens, pollen fragments, molds and other substances that contain proteins to which a large fraction of the public is allergic. It is logical to expect that when road dust particles are reentrained from the road surface into the atmosphere by vehicle traffic that the allergen content of the airborne particle mixture will be increased above the level that would prevail without the road dust emissions. The purpose of the research reported here was to quantify the allergen content of paved road dust and to estimate the magnitude of the road dust contribution to airborne allergen concentrations.

Atmospheric total suspended particulate matter (TSP) samples collected over the period October 1995 to May 1996 by the South Coast Air Quality Management District at central Los Angeles, Long Beach and Rubidoux, CA, were examined. Atmospheric PM_{10} samples collected over the same time period at Rubidoux were evaluated as well. Paved road dust samples were collected monthly by vacuum

sweeping defined areas of the surface streets near to these three air monitoring sites. The paved road dust source samples were sieved to eliminate particles larger than 37 to 55 μm particle diameter. Samples were then resuspended in air in the laboratory and recollected by TSP and PM_{10} high volume samplers. This was necessary to obtain pure road dust samples having particle size characteristics similar to airborne TSP and PM_{10} samples.

The paved road dust and atmospheric particle samples were chemically analyzed to determine their elemental composition. The paved road dust and airborne particle samples were extracted and the protein content of the samples was determined. It was found that the relative protein content of the airborne particle samples (μg protein/ g particulate matter supplied to the extraction process) was roughly an order of magnitude higher than in the paved road dust alone.

The specific allergen content of the paved road dust samples was determined for more than 20 allergen source materials (e. g. pure pollen grain samples, pure dog and cat dander, pure mold samples). This analysis was performed using AlaSTAT inhibition assays. In this assay the paved road dust protein extracts were evaluated for their ability to bind to the IgE antibodies present in the blood serum of persons who are known to be clinically allergic to the substance of interest. Proteins that tracked the patient serum response to 20 specific allergen sources were detected in one or more road dust samples including molds, tree pollens, weed pollens, grass pollens and animal dander. The most abundant allergens found in the paved road dust samples were Cladosporium mold, sycamore, Russian thistle,

lamb's quarters and mountain cedar allergens. No natural rubber latex allergen was found in this paved road dust from surface streets.

Upper limit estimates of the paved road dust contribution to atmospheric particle concentrations were obtained by matching the elemental composition of paved road dust to atmospheric particle samples. It was estimated that up to 36% to 64% of the airborne TSP mass and 26% to 33% of the airborne PM_{10} particle mass came from paved road dust. Based on overall protein binding to the IgE antibodies present in the blood serum from an atopic pool of patients who are broadly allergic to many substances, it was estimated that 0.5% to 13% of the allergenicity of the atmospheric TSP samples and 2% to 8% of the allergenicity of the PM_{10} samples examined was contributed by suspended paved road dust. The lowest values (0.5%) were measured at the central Los Angeles site where little vegetation and domestic activity takes place. The higher values were observed at the Long Beach and Rubidoux sites. These estimates represent upper limits derived under the premise that paved road dust is the major source of the mineral dust in the atmosphere near these air monitoring sites.

Introduction

Recent epidemiological studies suggest a correlation between exposure to particulate air pollution and several adverse health effects, including acute respiratory symptoms (reviewed in Dockery and Pope, 1994, and references therein). Exposure to environmental allergens can cause allergic disease that is mediated by IgE antibodies. The health effects of allergic disease range in severity from contact urticaria, rhinitis and asthma to anaphylaxis and death. Blood tests show that about 40% of the population have developed IgE antibodies against environmental allergens; about 20% of the members of the general public demonstrate upper respiratory symptoms typical of rhinitis (hay fever) and about 10% show lower respiratory symptoms characteristic of asthma (Pope et al., 1993). These acute respiratory effects are an allergic response to inhaled airborne particles that contain specific proteins. While many proteins are derived from natural sources such as plant pollens, animal dander or dust mites, other allergens are released from anthropogenic air pollution sources that use or process contemporary organic materials (Miguel et al., 1996). Allergen-containing airborne particles vary widely in shape and size (Owen et al., 1992 and references there in). Many of the unbroken source particles are above the 10 μm diameter particulate size that can be inhaled easily and may not be collected by current routine air monitoring procedures for PM_{10}. However, particle fracture, followed by mixing of the proteinaceous fragments and/or cytoplasmic cellular contents with other ambient

particles can lead to the presence of allergenic activity associated with smaller particles (Busse et al.,1972; Knox, 1993).

Total suspended particles (TSP) and particles with an aerodynamic diameter smaller than 10 μm (PM_{10}), collected at air monitoring stations, are normally characterized in terms of inorganic and organic chemical composition, but have not been systematically characterized in terms of either their allergen content or the allergen sources that contribute to TSP and PM_{10} concentrations. Paved road dust can be resuspended by moving vehicles: paved road dust is a major component of fine particles (PM_2) (Schauer et al., 1996) as well as PM_{10} in southern California (Watson et al.,1994; Air Resources Board, 1993). Previous chemical characterization shows that paved road dust is an extremely complex mixture of soil dust, deposited motor vehicle exhaust, tire dust, brake dust, biological material etc. (Rogge et al., 1993). There is an excellent chance that paved road dust contains allergens deposited on the road that become airborne by virtue of motor vehicle traffic over the road, thereby increasing atmospheric allergen concentrations to above the levels that would be experienced without motor vehicle traffic.

The present study examines paved road dust and atmospheric particulate matter as sources for allergen exposure. The allergens present in paved road dust at three sites in southern California are detected and characterized. The relative allergenic activity of paved road dust particles and airborne particulate matter is also determined. Finally, the paved road dust contribution to airborne particle concentrations and airborne allergen concentrations is estimated.

Materials and Methods

Sample Acquisition. The present study uses airborne particulate matter samples and paved road dust samples collected at 3 air quality monitoring sites within the greater Los Angeles area. As part of their routine air monitoring the South Coast Air Quality Management District (SCAQMD) collected airborne TSP samples on glass fiber filters by high volume sampling (1300 lpm for 24 hrs). These samples were collected every 6^{th} day during the period October 1995 – May 1996 at Long Beach, central Los Angeles and Rubidoux, CA. Airborne PM_{10} samples were collected on quartz fiber filters by high volume samplers at the Rubidoux site, on the same schedule and over the same time period. As soon as possible after sampling, filters were brought back to the SCAQMD from the field in pre-baked aluminum foil pouches. After routine gravimetric mass determination, a portion of each filter was placed in an annealed glass jar with a solvent-washed Teflon lid liner and stored at – 25° C. Three quarters of each high volume sampler filter taken at the Rubidoux and Los Angeles sites and one half of each filter taken at the Long Beach site were made available by the SCAQMD for use in the present study.

Paved road dust was vacuumed from the surface of paved roads in the vicinity of each of the SCAQMD ambient air monitoring sites studied. During sample collection polyvinyl chloride gloves were used to handle the samples and samples were returned from the field in autoclaved polyethylene bags to prevent unnecessary protease contamination. The samples were collected monthly at each of the three sites during the same period as the atmospheric samples. To create

road dust samples having a particle size range similar to atmospheric TSP samples, the road dust samples were progressively sieved through Tyler-equivalent sieves with mesh sizes of 28, 48, 100, 200, and 400 by shaking for 30 min on a Ro-Tap testing sieve shaker (W. S. T. Tyler Co., Cleveland, OH). Particles passing through a 400 mesh sieve in principle should have minor-axis dimensions of 37 μm and smaller. Two four-month composites (Oct – Jan and Feb – May) of paved road dust were created for each of the sampling sites by combining 400 mesh and smaller material that represented a constant area of street surface vacuumed outside of each monitoring site for each of the monthly sampling periods. In this way, those months having a heavier loading of road dust per unit surface area on the streets are more heavily represented in each composite road dust sample.

Size-fractionation of paved road dust. The paved road dust composites were further size-fractionated to match the TSP and PM_{10} atmospheric samples. Two different particle size-fractionation schemes were used, depending on the amount of end material required. More material was needed for the allergen characterization than for chemical characterization of paved road dust.

Allergen characterization. For the large scale production of material required in the allergen characterization, it was necessary to resuspend and collect a large amount of paved road dust. A particle resuspension chamber (1.5 m x 1.5 m x 0.76 m) was constructed to encase the 10 μm size selective head of a Graseby-Anderson PM_{10} high volume sampler. This method was used to artificially produce two PM_{10}-equivalent paved road dust composites that would parallel the Oct-Jan and Feb-

May airborne PM_{10} samples taken at the Rubidoux site. Samples of the 400 mesh material collected near the Rubidoux site were introduced into the resuspension chamber by injecting compressed air through the top of a 500 ml side-arm flask containing the 400 mesh filtered road dust material. Size-fractionated PM_{10}-equivalent paved road dust was collected by drawing the resuspended particles through the PM_{10} inlet of the PM_{10} high volume sampler onto pre-baked (550 °C for 16 h) quartz fiber filters (20.3 cm x 25.3 cm Pallflex QAO). Each 400-mesh road dust composite was also resuspended and size-fractionated to match the atmospheric TSP samples. The same fractionation procedure used to produce the PM_{10} road dust samples was used to produce TSP road dust samples except that a Graseby-Anderson high volume sampler with a TSP inlet instead of the PM_{10} size selective head was used for the collection of total suspended particulate matter. A smaller chamber (0.85 m x 0.86 m x 1.37 m) was also constructed to accommodate the TSP sampler.

Chemical analysis. A much smaller sampling system was used for the size-fractionation of paved road dust destined for chemical analysis. The composites of paved road dust created from material passed through a 400 mesh size Tyler-equivalent sieve were further fractionated according to size to yield fine (<2 μm), PM_{10} (<10 μm) and TSP (total suspended particulate) components. The sieved material was resuspended, introduced into a glove box (volume 640 l) and sampled simultaneously through a fine particle cyclone separator (John and Reischl, 1980), operated at 28.5 l/min, and an ambient PM_{10} sampler head, operated at 16.6 l/min (Solomon et al, 1989). Downstream of the devices used to create each size cut, the

total air flows were divided into three equal parallel streams. These three streams were then filtered through the following filter substrates: (a) a pre-baked (550 °C for 10 h) quartz fiber filter (47 mm diameter, Pallflex 2500 QAO) for elemental and organic carbon analysis (EC/OC); (b) a Teflon filter (47 mm diameter, 2 μm pore size Teflo, Gelman) for gravimetric determination of particle mass and for trace elemental analysis by X-ray fluorescence (XRF) and (c) a second Teflon filter for ionic species analysis by ion chromatography and colorimetry. In addition, several open-faced filter samplers located below a fallout shield were placed in the glove box and used to collect TSP-equivalent paved road dust samples for physical and chemical characterization. Three of these open-faced filter holders were each operated at an air flow rate of 10 lpm and were used to collect samples on quartz and Teflon filter material for subsequent chemical characterization as was described for the fine particle and PM_{10} samples. The TSP sampler also contained a filter (47 mm, 0.22 μm pore size, Millipore) operated at a flow rate of 1.25 lpm for particle size evaluation by optical microscopy. Three additional shielded open-face filter samplers operated at 14 lpm were run in parallel. These were used for the collection of TSP-equivalent paved road dust onto 2 glass microfiber filters (47 mm diameter, Whatman EPM 2000), a substrate suitable for trace element analysis by inductively coupled plasma mass spectrometry (ICP-MS) and onto a Teflon filter for use in gravimetric mass determination.

Chemical characterization. The size-fractionated paved road dust source samples collected on quartz fiber filters were analyzed for elemental and organic carbon by

the thermal evolution and combustion method described by Birch and Cary (1996). One Teflon filter of each set was analyzed for 38 trace elements by X-ray fluorescence (Dzubay, 1977) while the second Teflon filter of each set was analyzed for ionic substances by ion chromatography (Mueller et al, 1978), atomic absorption spectrophotometry and colorimetry (Solórzano, 1969).

Nitric acid extracts of the high volume sampler filters, containing airborne TSP collected at the atmospheric monitoring sites, were provided by the SCAQMD after they had performed their routine analysis for lead. Nitric acid extracts of the size-fractionated TSP-equivalent paved road dust source samples were prepared by the same modified EPA designated equivalent method No. EQL-0380-043. These nitric acid extracts were analyzed for selected trace elements by inductively coupled plasma mass spectrometry (ICP-MS; Berg, 1993in order to compare the trace elements distribution in the paved road dust source samples with the atmospheric samples.

Allergen extraction and protein determination. Filters containing each of the 4-month paved road dust source sample composites and atmospheric sample filters composited at each site on a monthly basis were placed in 500 ml HDPE wide-mouth jars. These jars had been previously siliconized (treated with 1% dimethyldichlorosilane for 15 min) to prevent protein adhesion to container walls. Fifty ml of chilled extraction buffer (10 mM $NaPO_4$, 2 mM phenylmethyl sulfonyl fluoride, 2.5 mM EDTA, 0.02% Na azide, pH 7.5) were added for each 20.3 cm x 25.4 cm high volume filter sample equivalent. Each sample was allowed to extract

overnight (~16 h) in a cold room at 4 °C, was filtered through a cellulose acetate filter (pore size of 0.2 um, Nalgene) and finally washed with 75 ml of cold sterile water. The filtered wash was combined with the initial filtrate and dialyzed (Spectra/por 3 dialysis tubing – MWCO 3500) against three changes (3.5 l) of cold sterile H_2O containing 0.02% Na azide. After lyopholization, the sample was resuspended in chilled resuspension buffer (10 mM $NaPO_4$, 10 µm leupeptin, 1 mM EDTA, 1 µM pepstatin, 0.2 mM aminoethylbenzene sulfonyl fluoride, 0.02% azide in sterile H_20). Protein concentrations were measured using the bicinchoninic acid protein assay (Sigma Chemical Co., St Louis, MO) according to instructions of the supplier (Stoscheck, 1990).

Inhibition immunoassay for allergens. The allergen content in the environmental samples was determined by the AlaSTAT-inhibition assay (Diagnostic Products Co., Los Angeles) which has been previously described in detail (Miguel et al, 1996). This is an ELISA (enzyme labeled immunoassay) in which foreign allergen from the environmental samples competes with a known amount of labeled allergen for the opportunity to bind to IgE antibody from the sera of patients who are sensitive to the allergen being tested. The more environmental allergen that is present in a sample tested, the more inhibition of labeled allergen binding to the IgE antibodies occurs. The assay is performed in the liquid phase but the labeled allergen is tagged with biotin. This allows for the attachment of the final end point species (labeled allergen-IgE complex) to a solid support. To determine allergens in environmental sample extracts, the AlaSTAT assays were performed according to the supplier's

instructions, except that serial dilutions of the test extracts (10 µl) were added to the allergen-specific patient sera prior to addition of the biotin-tagged allergen. Patient serum pools were created by combining the sera from 3 to 7 patients demonstrating a clinical sensitivity for the allergen being tested. Each immunoassay was run in duplicate. A control extract made from each pure allergen source material was run in parallel with the extracts of the environmental samples. Inhibition curves were constructed by varying the amount of protein from each control or environmental sample added to the test. The mass of protein eliciting a 50% inhibition response in each assay system was determined from the dose response curves. To conserve scarce environmental sample material, the amount of protein eliciting a 50% inhibition response was in some cases judged from a small number of dose points extrapolated along dose response curves drawn parallel to more complete inhibition curves which were constructed for the pure allergen control samples. Since the protein mass extracted from each milligram of original road dust source material or airborne particulate matter sample was known, it was possible to relate the protein addition needed to reach 50% inhibition in each bioassay back to the mass of paved road dust or airborne particles that had to be processed in order to produce that result.

Human IgE immunoblots. Immunoblots were performed as previously described (Miguel et al, 1996) except samples were applied directly to 0.45 µm pore size nitrocellulose membranes, using either a dot or a slot microfiltration apparatus (Bio-Rad Laboratories, New York). Airborne particulate and paved road dust

environmental samples were applied at 2 concentrations. Eight serial 3.5 fold dilutions were applied for each control sample that was prepared from pure allergen source material (e.g. specific pollen samples). The nitrocellulose membranes were blocked and then incubated for 2 h at room temperature with a pool of human atopic sera for the detection of IgE-binding allergens. After washing, the membranes were incubated for 1 h at room temperature in alkaline phosphatase conjugated mouse monoclonal anti-human IgE (Diagnostic Products Co.) at a concentration of 2 µg/ml and were then developed. The relative color development, reflecting the relative amount of IgE bound, was determined by optical density using an imaging TV camera system (UVP gel documentation system, UVP Inc., Upland, CA). Dose response curves (optical density peak height vs. µg protein applied) were linear over a range of 1.5 orders of magnitude with respect to protein applied. The optical densities of the dot and slot patterns developed for the environmental samples were then compared to the densities of the pure control allergen source material samples to determine the approximate allergenic potency of the proteins present.

Results

Characterization of paved road dust source samples and airborne particulate matter. A major objective of this study was to evaluate the potential role of resuspended paved road dust as a source of allergens encountered in airborne samples. To estimate the contribution of paved road dust to atmospheric particulate mass concentrations, chemical characterization of both the paved road dust source

samples and the ambient atmospheric samples of equivalent particle size is required. To accomplish this, paved road dust was first fractionated according to size. Its size distribution was then determined. Paved road dust samples, collected from three sites in the greater Los Angeles area as described in Methods, were sieved to obtain material that passed through a 400 mesh Tyler-equivalent screen. Microscopic imaging analysis showed that the particle-size distribution ranging up to 55 μm maximum particle diameter with a peak in the particle mass distribution at 30 μm particle diameter for the sieved road dust samples collected near the central Los Angeles and Long Beach sites. The peak in the particle size distribution for the Rubidoux site was at 40 μm particle diameter. This is comparable to the size distribution expected for atmospheric TSP. Intact pollen grains and mold spores were present in the sieved road dust samples, but at a much lower ratio to other particles than was the case for the atmospheric samples.

Figure 1 shows the mass size distribution of the resuspended and size-classified paved road dust source samples. About 50% of the TSP road dust source material at the Los Angeles and Long Beach sites and approximately 70% for the Rubidoux site is present in the PM_{10} fraction during the two paved road dust collection periods. Roughly 3% to 9% of the TSP-size road dust source material was present in fine particle sizes below 2 μm aerodynamic diameter.

Each size fraction of the paved road dust source samples separated and described in Figure 1 was chemically analyzed. The resulting source profiles, delineating the chemical composition of paved road dust samples, can be found in Table 1. Those species whose concentration in the road dust samples was greater

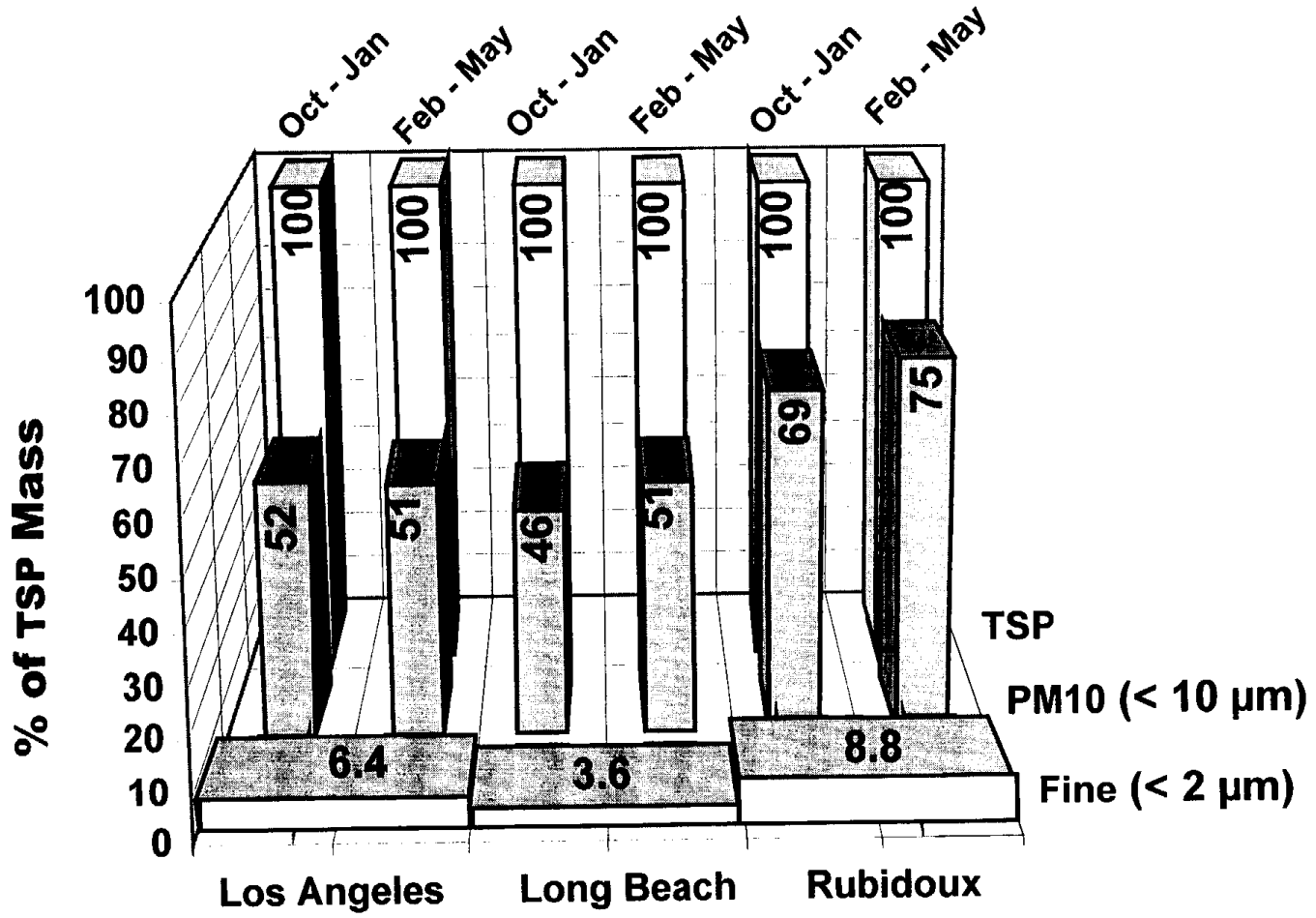

Figure 1. Size Distribution of Paved Road Dust at Los Angeles, Long Beach and Rubidoux during two time periods.

Table 1. Chemical Composition of the TSP, PM_{10} and PM_2 Components of Size - fractionated Paved Road Dust Source Samples from Los Angeles, Long Beach and Rubidoux, CA, 1995 -1996.

Los Angeles

Chemical Species	TSP Oct - Jan	TSP Feb - May	PM_{10} Oct - Jan	PM_{10} Feb - May	PM_2 Oct - May
	Weight % of Particle Mass (Average ± Std)				
Al	**5.02 ± 1.47**	**4.20 ± 1.23**	**8.34 ± 2.44**	**9.01 ± 2.64**	**4.12 ± 0.08**
Si	**15.21 ± 4.75**	**13.97 ± 4.37**	**25.04 ± 7.83**	**27.64 ± 8.64**	**13.75 ± 0.08**
P	**0.05 ± 0.02**	**0.04 ± 0.02**	**0.09 ± 0.04**	**0.10 ± 0.05**	**0.12 ± 0.02**
S	**0.24 ± 0.02**	**0.33 ± 0.02**	**0.42 ± 0.03**	**0.70 ± 0.03**	**0.81 ± 0.04**
Cl	0.00 ± 0.03	0.02 ± 0.03	0.00 ± 0.04	**0.13 ± 0.04**	**0.08 ± 0.02**
K	**1.07 ± 0.21**	**0.97 ± 0.19**	**1.68 ± 0.32**	**1.91 ± 0.37**	**1.22 ± 0.03**
Ca	**1.47 ± 0.24**	**1.58 ± 0.25**	**2.29 ± 0.37**	**3.05 ± 0.49**	**2.06 ± 0.03**
Ti	**0.26 ± 0.03**	**0.26 ± 0.03**	**0.42 ± 0.03**	**0.44 ± 0.04**	**0.34 ± 0.08**
V	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.02	0.01 ± 0.03	0.00 ± 0.05
Cr	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.02 ± 0.01**
Mn	**0.04 ± 0.00**	**0.04 ± 0.00**	**0.07 ± 0.00**	**0.07 ± 0.00**	**0.06 ± 0.01**
Fe	**3.45 ± 0.01**	**3.19 ± 0.01**	**5.54 ± 0.01**	**6.09 ± 0.01**	**5.86 ± 0.02**
Co	0.00 ± 0.05	0.01 ± 0.05	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
Ni	0.00 ± 0.00	0.00 ± 0.00	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**
Cu	**1.10 ± 0.00**	**1.01 ± 0.00**	**1.84 ± 0.01**	**2.07 ± 0.01**	**2.43 ± 0.01**
Zn	**0.52 ± 0.00**	**0.49 ± 0.00**	**0.86 ± 0.00**	**0.99 ± 0.00**	**1.14 ± 0.01**
Ga	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.02
As	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.16	0.00 ± 0.18	0.00 ± 0.20
Se	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.01
Br	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Rb	0.00 ± 0.00	0.00 ± 0.00	**0.01 ± 0.00**	**0.01 ± 0.00**	0.01 ± 0.00
Sr	**0.03 ± 0.00**	**0.05 ± 0.00**	**0.04 ± 0.00**	**0.12 ± 0.00**	**0.05 ± 0.00**
Y	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Zr	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**	0.01 ± 0.01
Mo	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Pd	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.04
Ag	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.05
Cd	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.03	0.01 ± 0.05
In	0.00 ± 0.02	0.00 ± 0.03	0.00 ± 0.02	0.00 ± 0.03	0.00 ± 0.06
Sn	**0.05 ± 0.02**	**0.07 ± 0.02**	**0.08 ± 0.02**	**0.11 ± 0.02**	**0.10 ± 0.05**
Sb	0.01 ± 0.03	0.01 ± 0.04	0.00 ± 0.03	0.00 ± 0.04	0.00 ± 0.09
Ba	0.05 ± 0.11	0.02 ± 0.14	0.05 ± 0.12	0.12 ± 0.10	0.18 ± 0.32
La	0.02 ± 0.15	0.02 ± 0.18	0.00 ± 0.15	0.00 ± 0.20	0.05 ± 0.43
Au	0.01 ± 0.02	0.00 ± 0.02	0.00 ± 0.03	0.01 ± 0.04	0.00 ± 0.04
Hg	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Tl	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.04
Pb	**0.57 ± 0.01**	**0.54 ± 0.01**	**1.02 ± 0.01**	**1.14 ± 0.01**	**1.29 ± 0.02**
U	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.01
EC	0.49 ± 0.31	0.71 ± 0.38	**1.51 ± 0.35**	**1.01 ± 0.40**	0.90 ± 0.88
OC	**8.38 ± 0.69**	**11.90 ± 0.91**	**10.95 ± 0.82**	**14.49 ± 1.05**	**15.12 ± 1.58**
Cl-	0.00 ± 0.05	0.02 ± 0.04	0.01 ± 0.04	0.04 ± 0.05	0.00 ± 0.11
NO3-	0.08 ± 0.08	0.08 ± 0.07	**0.09 ± 0.03**	**0.15 ± 0.07**	0.12 ± 0.17
SO4=	**0.27 ± 0.05**	**0.63 ± 0.04**	**0.31 ± 0.04**	**1.10 ± 0.05**	**0.95 ± 0.11**
NH4+	0.00 ± 0.02	0.00 ± 0.02	**0.10 ± 0.02**	**0.09 ± 0.02**	0.00 ± 0.05
Na+	0.05 ± 0.15	**0.42 ± 0.15**	0.27 ± 0.15	0.27 ± 0.15	0.00 ± 0.15

Table 1. (continued)

Long Beach

Chemical Species	TSP Oct - Jan	TSP Feb - May	PM_{10} Oct - Jan	PM_{10} Feb - May	PM_2 Oct - May
	Weight % of Particle Mass (Average ± Std)				
Al	**3.77 ± 1.11**	**2.80 ± 0.82**	**5.05 ± 1.48**	**7.32 ± 2.15**	**4.01 ± 0.06**
Si	**12.46 ± 3.89**	**9.03 ± 2.82**	**16.78 ± 5.25**	**23.98 ± 7.49**	**14.22 ± 0.06**
P	**0.06 ± 0.03**	0.05 ± 0.03	**0.09 ± 0.04**	**0.12 ± 0.05**	**0.15 ± 0.02**
S	**0.20 ± 0.01**	**0.14 ± 0.01**	**0.26 ± 0.01**	**0.38 ± 0.02**	**0.62 ± 0.02**
Cl	**0.05 ± 0.02**	**0.06 ± 0.02**	**0.06 ± 0.02**	**0.11 ± 0.04**	**0.10 ± 0.02**
K	**0.98 ± 0.19**	**0.72 ± 0.14**	**1.22 ± 0.24**	**1.77 ± 0.34**	**1.57 ± 0.02**
Ca	**2.04 ± 0.33**	**1.40 ± 0.23**	**2.53 ± 0.41**	**3.61 ± 0.58**	**4.63 ± 0.03**
Ti	**0.16 ± 0.05**	**0.12 ± 0.05**	**0.22 ± 0.06**	**0.32 ± 0.07**	**0.39 ± 0.06**
V	0.00 ± 0.04	0.00 ± 0.03	0.01 ± 0.03	0.00 ± 0.04	0.02 ± 0.04
Cr	0.00 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	**0.02 ± 0.01**
Mn	**0.04 ± 0.00**	**0.03 ± 0.00**	**0.05 ± 0.01**	**0.07 ± 0.01**	**0.10 ± 0.01**
Fe	**2.28 ± 0.01**	**1.68 ± 0.01**	**2.85 ± 0.01**	**4.25 ± 0.02**	**5.40 ± 0.02**
Co	0.00 ± 0.04	0.01 ± 0.03	0.00 ± 0.04	0.01 ± 0.07	0.00 ± 0.08
Ni	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	**0.01 ± 0.00**
Cu	**0.04 ± 0.00**	**0.04 ± 0.00**	**0.16 ± 0.00**	**0.12 ± 0.00**	**0.15 ± 0.00**
Zn	**0.09 ± 0.00**	**0.08 ± 0.00**	**0.18 ± 0.00**	**0.20 ± 0.00**	**0.26 ± 0.00**
Ga	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
As	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02
Se	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Br	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Rb	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	**0.01 ± 0.00**	**0.01 ± 0.00**
Sr	**0.03 ± 0.00**	**0.02 ± 0.00**	**0.04 ± 0.00**	**0.04 ± 0.00**	**0.05 ± 0.00**
Y	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
Zr	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	**0.01 ± 0.00**	**0.01 ± 0.00**
Mo	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Pd	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.01 ± 0.03
Ag	0.00 ± 0.03	0.02 ± 0.03	0.01 ± 0.03	0.00 ± 0.04	0.00 ± 0.03
Cd	0.00 ± 0.03	0.01 ± 0.03	0.02 ± 0.04	0.00 ± 0.04	0.00 ± 0.04
In	0.00 ± 0.04	0.00 ± 0.04	0.00 ± 0.04	0.00 ± 0.05	0.00 ± 0.04
Sn	0.01 ± 0.05	0.00 ± 0.05	0.00 ± 0.05	0.01 ± 0.06	0.00 ± 0.05
Sb	0.00 ± 0.05	0.00 ± 0.06	0.00 ± 0.06	0.00 ± 0.07	0.00 ± 0.06
Ba	0.08 ± 0.19	0.06 ± 0.20	0.03 ± 0.22	0.08 ± 0.26	0.05 ± 0.21
La	0.07 ± 0.26	0.00 ± 0.27	0.00 ± 0.29	0.00 ± 0.35	0.07 ± 0.29
Au	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Hg	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Tl	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Pb	**0.05 ± 0.01**	**0.04 ± 0.01**	**0.09 ± 0.01**	**0.10 ± 0.01**	**0.14 ± 0.01**
U	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
EC	**2.81 ± 0.76**	0.70 ± 0.56	1.20 ± 0.71	0.90 ± 0.64	**1.80 ± 0.62**
OC	**9.08 ± 1.10**	**14.73 ± 1.24**	**16.74 ± 1.46**	**12.18 ± 1.20**	**15.26 ± 1.28**
Cl-	0.00 ± 0.06	0.03 ± 0.07	0.01 ± 0.10	0.03 ± 0.07	0.07 ± 0.07
NO3-	0.01 ± 0.10	0.04 ± 0.10	0.00 ± 0.15	0.03 ± 0.11	0.03 ± 0.11
SO4=	**0.21 ± 0.06**	**0.45 ± 0.07**	**0.48 ± 0.10**	**0.51 ± 0.07**	**0.92 ± 0.07**
NH4+	**0.12 ± 0.03**	**0.11 ± 0.03**	**0.21 ± 0.04**	0.00 ± 0.03	0.00 ± 0.03
Na+	0.37 ± 0.15	0.05 ± 0.15	**0.70 ± 0.16**	0.11 ± 0.16	**0.32 ± 0.15**

Table 1. **(continued)**

Rubidoux

Chemical Species	TSP Oct - Jan	TSP Feb - May	PM_{10} Oct - Jan	PM_{10} Feb - May	PM_2 Oct - May
	Weight % of Particle Mass (Average ± Std)				
Al	**5.98 ± 1.76**	**6.38 ± 1.87**	**11.35 ± 3.33**	**11.03 ± 3.24**	**5.02 ± 0.07**
Si	**17.90 ± 5.59**	**19.20 ± 6.00**	**32.56 ± 10.18**	**32.32 ± 10.10**	**15.49 ± 0.06**
P	**0.10 ± 0.05**	**0.14 ± 0.07**	**0.18 ± 0.08**	**0.17 ± 0.08**	**0.12 ± 0.01**
S	**0.16 ± 0.02**	**0.18 ± 0.02**	**0.24 ± 0.02**	**0.23 ± 0.02**	**0.32 ± 0.01**
Cl	**0.06 ± 0.03**	0.04 ± 0.07	**0.10 ± 0.04**	**0.10 ± 0.04**	**0.07 ± 0.02**
K	**1.47 ± 0.28**	**1.54 ± 0.30**	**2.73 ± 0.53**	**2.61 ± 0.50**	**1.83 ± 0.02**
Ca	**2.57 ± 0.41**	**2.58 ± 0.42**	**4.42 ± 0.71**	**4.37 ± 0.70**	**3.96 ± 0.03**
Ti	**0.32 ± 0.09**	**0.27 ± 0.12**	**0.50 ± 0.08**	**0.54 ± 0.10**	**0.43 ± 0.05**
V	0.02 ± 0.05	0.00 ± 0.09	0.00 ± 0.05	0.03 ± 0.06	0.00 ± 0.03
Cr	0.01 ± 0.01	0.00 ± 0.03	**0.02 ± 0.01**	0.02 ± 0.01	**0.03 ± 0.01**
Mn	**0.10 ± 0.01**	**0.10 ± 0.01**	**0.17 ± 0.01**	**0.17 ± 0.01**	**0.17 ± 0.01**
Fe	**3.72 ± 0.02**	**3.78 ± 0.02**	**6.74 ± 0.02**	**6.41 ± 0.02**	**6.34 ± 0.02**
Co	0.01 ± 0.06	0.01 ± 0.06	0.00 ± 0.11	0.00 ± 0.10	0.01 ± 0.10
Ni	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	**0.01 ± 0.00**
Cu	**0.02 ± 0.01**	**0.03 ± 0.01**	**0.11 ± 0.00**	**0.05 ± 0.01**	**0.09 ± 0.00**
Zn	**0.06 ± 0.01**	**0.07 ± 0.01**	**0.16 ± 0.01**	**0.12 ± 0.01**	**0.16 ± 0.00**
Ga	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
As	0.00 ± 0.01	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02
Se	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.00
Br	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.00
Rb	0.00 ± 0.00	0.01 ± 0.01	**0.01 ± 0.00**	0.01 ± 0.00	**0.01 ± 0.00**
Sr	**0.05 ± 0.00**	**0.04 ± 0.01**	**0.08 ± 0.00**	**0.07 ± 0.00**	**0.07 ± 0.00**
Y	0.00 ± 0.01	0.00 ± 0.01	**0.01 ± 0.00**	0.00 ± 0.01	0.00 ± 0.00
Zr	0.01 ± 0.01	0.00 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.00
Mo	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.01	0.00 ± 0.02	0.00 ± 0.01
Pd	0.00 ± 0.04	0.01 ± 0.06	0.00 ± 0.04	0.00 ± 0.05	0.00 ± 0.03
Ag	0.01 ± 0.05	0.00 ± 0.07	0.00 ± 0.05	0.00 ± 0.06	0.00 ± 0.03
Cd	0.00 ± 0.05	0.00 ± 0.07	0.00 ± 0.05	0.02 ± 0.06	0.00 ± 0.03
In	0.00 ± 0.06	0.00 ± 0.08	0.00 ± 0.06	0.00 ± 0.07	0.01 ± 0.04
Sn	0.02 ± 0.08	0.00 ± 0.10	0.01 ± 0.07	0.03 ± 0.09	0.01 ± 0.05
Sb	0.00 ± 0.09	0.01 ± 0.12	0.00 ± 0.08	0.00 ± 0.11	0.00 ± 0.06
Ba	0.00 ± 0.34	0.16 ± 0.43	0.19 ± 0.29	0.00 ± 0.38	0.15 ± 0.20
La	0.00 ± 0.45	0.17 ± 0.58	0.00 ± 0.39	0.00 ± 0.51	0.01 ± 0.27
Au	0.01 ± 0.02	0.00 ± 0.02	0.01 ± 0.02	0.01 ± 0.02	0.00 ± 0.01
Hg	0.00 ± 0.01	0.00 ± 0.02	0.00 ± 0.01	0.00 ± 0.02	0.00 ± 0.01
Tl	0.00 ± 0.01	0.00 ± 0.02	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Pb	**0.03 ± 0.01**	**0.04 ± 0.02**	**0.08 ± 0.01**	**0.07 ± 0.01**	**0.09 ± 0.01**
U	0.00 ± 0.01	0.00 ± 0.02	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
EC	**2.70 ± 1.03**	0.49 ± 1.40	0.27 ± 0.65	0.45 ± 0.98	0.37 ± 0.53
OC	**7.53 ± 1.38**	**8.04 ± 1.83**	**8.12 ± 1.02**	**8.65 ± 1.42**	**10.30 ± 1.02**
Cl-	0.00 ± 0.13	0.00 ± 0.16	0.00 ± 0.09	0.00 ± 0.12	0.05 ± 0.07
NO3-	0.09 ± 0.20	0.14 ± 0.29	0.06 ± 0.13	0.05 ± 0.18	0.14 ± 0.10
SO4=	0.09 ± 0.13	0.15 ± 0.16	0.04 ± 0.09	0.23 ± 0.12	**0.54 ± 0.07**
NH4+	0.00 ± 0.06	0.00 ± 0.08	0.00 ± 0.04	0.00 ± 0.05	0.00 ± 0.03
Na+	0.00 ± 0.15	0.00 ± 0.15	0.00 ± 0.15	0.05 ± 0.15	0.26 ± 0.15

than zero by at least two standard errors of the analytical methods used to make the measurements are shown in bold face in Table 1. The chemical profiles were similar for the three locations, except for the abnormally high levels of lead, copper and zinc found in paved road dust near the central Los Angeles air monitoring site. This is in a heavily industrialized neighborhood. The relative abundance of iron, copper, zinc, lead and sulfur increased with decreasing particle size. A comparison of separate 4-month paved road dust composites collected at different time periods throughout the year did not show any systematic variation in chemical composition by season.

The atmospheric particulate matter used in the present study was collected by the South Coast Air Quality Management District as part of their routine sampling schedule. The TSP samples were collected on glass fiber filters at the Los Angeles, Long Beach and Rubidoux locations and on quartz fiber filters for the PM_{10} samples collected at Rubidoux. These filter substrates do not permit the determination of trace element concentrations by X-ray fluorescence (XRF), the method used above for the analysis of paved road dust. Thus nitric acid extracts of the atmospheric TSP and the size-fractionated TSP-equivalent paved road dust source samples were analyzed for selected trace elements by inductively coupled plasma mass spectrometry (ICP-MS). A comparison of the resulting chemical profiles for the airborne and paved road dust samples at all three locations is presented in Table 2. Comparison of the trace elements found in the paved road dust source samples obtained by the XRF and ICP-MS methods indicates that they are not systematically different from each other.

Table 2. Chemical Composition of Airborne TSP and Size - Fractionated TSP - Equivalent Paved Road Dust Samples from Central Los Angeles, Long Beach and Rubidoux During Oct 1995 - Jan 1996 and Feb 1996 - May 1996.

Los Angeles (Oct - Jan)

Component	Airborne	Road Dust
	Weight % of Particulate Mass (Ave ± Std)	
P 31	0.0781 ± 0.0012	0.1713 ± 0.0033
Cl 35	0.0247 ± 0.0009	0.0025 ± 0.0020
Ca 42	1.7764 ± 0.0346	1.1649 ± 0.0864
Ti 47	0.0352 ± 0.0005	0.1151 ± 0.0022
Ti 48	0.0359 ± 0.0005	0.1031 ± 0.0018
V 51	0.0077 ± 0.0001	0.0058 ± 0.0001
Mn 55	0.0271 ± 0.0003	0.0490 ± 0.0008
Fe 57	1.4958 ± 0.0159	2.9368 ± 0.0458
Co 59	0.0007 ± 0.0000	0.0014 ± 0.0000
Cu 65	0.1943 ± 0.0020	1.5481 ± 0.0186
Zn 66	0.1378 ± 0.0015	0.7471 ± 0.0135
Br 79	0.0087 ± 0.0003	0.0012 ± 0.0003
Rb 85	0.0007 ± 0.0000	0.0027 ± 0.0001
Sr 88	0.0140 ± 0.0002	0.0207 ± 0.0003
Pb 208	0.0459 ± 0.0005	0.7877 ± 0.0099

Los Angeles (Feb - May)

Component	Airborne	Road Dust
	Weight % of Particulate Mass (Ave ± Std)	
P 31	0.0784 ± 0.0026	0.1873 ± 0.0026
Cl 35	0.2581 ± 0.0058	0.0023 ± 0.0058
Ca 42	7.8075 ± 0.1775	1.3775 ± 0.1775
Ti 47	0.0487 ± 0.0014	0.1081 ± 0.0014
Ti 48	0.0644 ± 0.0016	0.0974 ± 0.0016
V 51	0.0100 ± 0.0002	0.0051 ± 0.0002
Mn 55	0.0291 ± 0.0008	0.0490 ± 0.0008
Fe 57	1.5839 ± 0.0449	3.0091 ± 0.0449
Co 59	0.0014 ± 0.0000	0.0015 ± 0.0000
Cu 65	0.1649 ± 0.0033	1.4614 ± 0.0033
Zn 66	0.1939 ± 0.0055	0.7163 ± 0.0055
Br 79	0.0151 ± 0.0006	0.0010 ± 0.0006
Rb 85	0.0025 ± 0.0001	0.0024 ± 0.0001
Sr 88	0.0185 ± 0.0005	0.0683 ± 0.0005
Pb 208	0.0546 ± 0.0015	0.7441 ± 0.0015

Analysis of nitric acid extracts by inductively coupled mass spectrometry (ICP-MS)

Table 2. (continued)

Long Beach (Oct - Jan)

Component	Airborne	Road Dust
	Weight % of Particulate Mass (Ave ± Std)	
P 31	0.0618 ± 0.0011	0.1516 ± 0.0040
Cl 35	0.0844 ± 0.0022	0.0079 ± 0.0044
Ca 42	3.4245 ± 0.0555	2.3302 ± 0.1721
Ti 47	0.0396 ± 0.0005	0.0806 ± 0.0015
Ti 48	0.0442 ± 0.0006	0.0776 ± 0.0016
V 51	0.0127 ± 0.0001	0.0040 ± 0.0001
Mn 55	0.0253 ± 0.0003	0.0579 ± 0.0010
Fe 57	1.2512 ± 0.0139	2.2661 ± 0.0389
Co 59	0.0009 ± 0.0000	0.0011 ± 0.0001
Cu 65	0.2359 ± 0.0024	0.0739 ± 0.0023
Zn 66	0.1234 ± 0.0015	0.1500 ± 0.0019
Br 79	0.0146 ± 0.0004	0.0008 ± 0.0005
Rb 85	0.0014 ± 0.0000	0.0024 ± 0.0001
Sr 88	0.0127 ± 0.0002	0.0395 ± 0.0006
Pb 208	0.0359 ± 0.0004	0.0739 ± 0.0012

Long Beach (Feb - May)

Component	Airborne	Road Dust
	Weight % of Particulate Mass (Ave ± Std)	
P 31	0.0857 ± 0.0017	0.1697 ± 0.0038
Cl 35	0.5127 ± 0.0115	0.0051 ± 0.0030
Ca 42	5.6832 ± 0.1158	2.2155 ± 0.1328
Ti 47	0.0550 ± 0.0009	0.0749 ± 0.0017
Ti 48	0.0645 ± 0.0010	0.0709 ± 0.0014
V 51	0.0265 ± 0.0003	0.0042 ± 0.0001
Mn 55	0.0318 ± 0.0004	0.0586 ± 0.0009
Fe 57	1.6525 ± 0.0207	2.5838 ± 0.0504
Co 59	0.0011 ± 0.0000	0.0014 ± 0.0000
Cu 65	0.6528 ± 0.0066	0.0587 ± 0.0007
Zn 66	0.0998 ± 0.0016	0.1505 ± 0.0033
Br 79	0.0198 ± 0.0007	0.0008 ± 0.0004
Rb 85	0.0017 ± 0.0001	0.0023 ± 0.0001
Sr 88	0.0191 ± 0.0002	0.0191 ± 0.0002
Pb 208	0.0227 ± 0.0003	0.0608 ± 0.0009

Analysis of nitric acid extracts by inductively coupled mass spectrometry (ICP-MS)

Table 2. (continued)

Rubidoux (Oct - Jan)

Component	Airborne	Road Dust
	Weight % of Particulate Mass (Ave ± Std)	
P 31	0.1265 ± 0.0016	0.1597 ± 0.0051
Cl 35	0.0307 ± 0.0008	0.0040 ± 0.0049
Ca 42	5.9271 ± 0.0678	2.2044 ± 0.1823
Ti 47	0.0638 ± 0.0008	0.1433 ± 0.0030
Ti 48	0.0703 ± 0.0007	0.1314 ± 0.0022
V 51	0.0051 ± 0.0001	0.0071 ± 0.0002
Mn 55	0.0429 ± 0.0004	0.1257 ± 0.0019
Fe 57	1.5493 ± 0.0140	3.7744 ± 0.0610
Co 59	0.0007 ± 0.0000	0.0014 ± 0.0001
Cu 65	0.2661 ± 0.0023	0.0247 ± 0.0007
Zn 66	0.0893 ± 0.0010	0.0787 ± 0.0016
Br 79	0.0067 ± 0.0002	-0.0003 ± 0.0006
Rb 85	0.0019 ± 0.0000	0.0037 ± 0.0001
Sr 88	0.0190 ± 0.0002	0.0386 ± 0.0005
Pb 208	0.0237 ± 0.0003	0.0379 ± 0.0005

Rubidoux (Feb - May)

Component	Airborne	Road Dust
	Weight % of Particulate Mass (Ave ± Std)	
P 31	0.1477 ± 0.0021	0.1446 ± 0.0055
Cl 35	0.0583 ± 0.0016	0.0006 ± 0.0058
Ca 42	4.1815 ± 0.0598	2.2483 ± 0.2482
Ti 47	0.0613 ± 0.0008	0.1448 ± 0.0037
Ti 48	0.0645 ± 0.0008	0.1318 ± 0.0026
V 51	0.0076 ± 0.0001	0.0081 ± 0.0001
Mn 55	0.0355 ± 0.0004	0.1354 ± 0.0014
Fe 57	1.4416 ± 0.0144	5.8909 ± 0.0804
Co 59	0.0006 ± 0.0000	0.0017 ± 0.0001
Cu 65	0.5105 ± 0.0045	0.0333 ± 0.0006
Zn 66	0.0733 ± 0.0009	0.0865 ± 0.0017
Br 79	0.0067 ± 0.0003	0.0004 ± 0.0010
Rb 85	0.0014 ± 0.0000	0.0036 ± 0.0002
Sr 88	0.0128 ± 0.0001	0.0436 ± 0.0007
Pb 208	0.0158 ± 0.0002	0.0352 ± 0.0008

Analysis of nitric acid extracts by inductively coupled mass spectrometry (ICP-MS)

Extractable protein. The extractable protein levels from airborne particles and size-fractionated paved road dust source samples are presented in Table 3. Protein yields per gram of airborne particulate material are roughly an order of magnitude higher than the yields for paved road dust. Atmospheric protein concentrations were higher in the October to January period than for the February to May period. Results from the monthly composites indicate a peak in the months of November, December and January. The amount of protein associated with airborne particles during the October – January period was higher for the Los Angeles and Long Beach urban sites on the western side of the Los Angeles basin than for the more rural Rubidoux site that is located at the eastern end of the Air Basin surrounding Los Angeles. This pattern of peak concentration in the winter months on the western side of the Los Angeles Basin is typical of primary organic aerosol concentrations in general in this geographical area and occurs due to wintertime wind stagnation in Los Angeles (Gray et al., 1986). Results from the Rubidoux site showed that most of the protein present in the TSP samples also was associated with the PM_{10} fraction for both the atmospheric and the resuspended paved road dust material. This indicates that the bulk of the proteinaceous material would be readily inhalable.

Characterization of allergen content of paved road dust. The TSP-equivalent size-fractionated paved road dust samples were screened for the presence of source-specific allergens from 24 source materials. This was accomplished by measuring the ability of paved road dust protein extracts to inhibit each source

Table 3. Extractable Protein from Airborne Particles and Size - Fractionated Paved Road Dust.

Samples	Extractable Protein[a]		
	Airborne Particles		Paved Road Dust
	(mg/g)	(ug/m3)	(mg/g)
Los Angeles TSP			
Oct 95	25.78	2.54	
Nov 95	46.37	5.79	
Dec 95	49.65	5.24	
Jan 96	45.19	4.56	
Feb 96	29.41	1.78	
Mar 96	30.36	1.66	
Apr 96	26.56	1.80	
May 96	22.21	1.50	
Oct 95 – Jan 96	42.75	4.53	0.93
Feb 96 – May 96	27.44	1.68	1.04
Long Beach TSP			
Oct 95	25.92	2.31	
Nov 95	44.30	5.79	
Dec 95	46.10	4.84	
Jan 96	49.10	3.78	
Feb 96	28.26	1.44	
Mar 96	20.91	0.87	
Apr 96	10.98	0.58	
May 96	18.93	1.17	
Oct 95 – Jan 96	42.46	4.18	2.75
Feb 96 – May 96	20.56	1.01	4.54
Rubidoux TSP			
Oct 95	17.39	2.97	
Nov 95	22.83	3.74	
Dec 95	31.57	4.25	
Jan 96	40.19	2.95	
Feb 96	29.67	1.90	
Mar 96	26.91	1.74	
Apr 96	19.65	2.03	
May 96	16.63	2.06	
Oct 95 – Jan 96	28.70	3.48	3.75
Feb 96 – May 96	23.58	1.93	3.14
Rubidoux PM10			
Oct 95	22.31	2.39	
Nov 95	35.11	3.88	
Dec 95	33.42	3.23	
Jan 96	81.99	3.78	
Feb 96	48.34	2.07	
Mar 96	43.84	2.13	
Apr 96	31.41	2.14	
May 96	30.53	2.16	
Oct 95 – Jan 96	50.66	3.32	7.63
Feb 96 – May 96	39.00	2.12	5.43

[a] Protein yield/initial sample weight or air volume as assayed by the bicinchoninic acid method.

allergen-specific AlaSTAT immunoassay. The relative allergen concentration in the extract from the environmental samples added to each assay is proportional to the amount of inhibition. Table 4 shows the number of milligrams of TSP-sized paved road dust that must be extracted and supplied at the front end of the bioassay procedure in order to achieve 50% inhibition of the test system. This is referenced against the mass of pure control allergen source material (e.g. pure pollen) that must be processed to achieve the same result. Such a comparison is made possible by knowing the ratio of extracted protein mass to source material mass processed for each pure allergen source and for each environmental sample. The lower values indicate a higher potency (or allergen concentration) because less mass of initial material must be added to achieve an equivalent effect. Because the control curves for the various pure allergen source materials display such a large range of allergen potency, results obtained for the road dust environmental samples should be compared with the corresponding specific allergen control curve that was performed concurrently. The paved road dust and specific source allergenic material can be compared on the basis of relative allergenic potency by dividing the value given in Table 4 for the paved road dust sample by the value for the pure allergen source material. The paved road dust samples were a factor of $1x10^5$ to $3x10^5$ less potent per unit mass than the grass pollens, but only 8 to 35 and 42 to 110 fold less potent than the pure lamb's quarters and pure mountain cedar pollens respectively. This is not surprising. The road dust should be less potent than individual pure allergen source materials since road dust is a complex mixture that

Table 4. Allergens Present in Size-fractionated, TSP - Equivalent Paved Road Dust Source Samples from Three Locations in the Los Angeles Basin. Allergen-specific AlaSTAT-inhibition immunoassays were used to determine the mass of paved road dust that must be extracted to achieve 50% inhibition of the assay compared to the mass of pure allergen source material (e.g. pollen grain mass) processed to obtain equal inhibition as described in Methods. Blanks indicate values below the limit of detection. Allergen Symbol indicates: Mold (M), Tree (T), Weed (W), Grass (G), Animal dander (E).

Allergen			Allergenic Potency - mg original material processed to achieve 50% inhibition response						
			Pure Allergen Source Material	Los Angeles Road Dust		Long Beach Road Dust		Rubidoux Road Dust	
Symbol	Common name	Scientific name		Oct - Jan	Feb - May	Oct - Jan	Feb - May	Oct - Jan	Feb - May
M 2	Cladosporium Mold	*Cladosporium herbarum*	0.0252	16.5	16.0	13.3	27.1	14.4	25.1
T 11	Sycamore	*Plantanus occidentalls*	0.0777	66.5	69.1	38.0	19.1	22.3	37.3
W 11	Russian Thistle	*Salsola pestifer*	0.1108	18.1	40.1	53.5	15.2	23.1	22.0
W 10	Lambs Quarters	*Chenopodium album*	0.8600	28.7	47.5	7.1	30.4	10.7	10.4
T 6	Mountain Cedar	*Juniperus sabinoides*	0.4061	19.6	32.9	17.2	27.0	19.4	44.2
T 8	White Elm	*Ulmus americana*	0.2941	104.4	97.5	136.3	69.4	70.5	109.4
T 16	White Pine	*Pinus strobus*	0.0191	153.0	136.8	239.2	232.7	109.2	93.9
T 15	White Ash	*Fraxinus americana*	0.0209	250.0	111.7	161.0	53.8	75.6	35.2
T 7	White Oak	*Quercus alba*	0.1881	277.5	239.3	386.5	202.5	137.1	113.9
T2	Alder	*Alnus rugosa*	0.0020	270.4	175.1				
W 6	Mugwort	*Artemisia vulgaris*	0.0219	359.4	405.5	223.8	135.5	179.0	119.6
M 6	Alternaria Mold	*Alternaria alternata/tenuis*	0.1466	464.7	520.3	196.8	149.2	121.9	182.3
G 4	Meadow Fescue Grass	*Festuca elatior*	0.0024	568.7	346.4	320.9			247.3
E 5	Dog Dander-epithelium		0.0453	248.9	568.6	472.1	277.4	335.9	232.7
G 5	Perennial Rye Grass	*Lolium perenne*	0.0013	375.5	372.8				
T 9	Olive	*Olea europea*	0.0095	368.9					
W 2	Western Ragweed	*Ambrosia psilostachya*	0.1294	371.0	298.3				
T 23	Italian Cypress	*Cupressus sempervirens*	2.4492	315.7	282.3				
E 1	Cat Dander-epithelium		0.0360	825.5	713.8				
G2	Bermuda Grass	*Cynodon dactyion*	0.0039	1091.3					
G 11	Brome Grass	*Bromus inermis*	0.0046						
D 2	House Dust Mite	*Dermatophagoides farinae*	0.0020						
K 82	Natural Rubber Latex	*Hevea brasiliensis*	0.0058						
G 6	Timothy Grass	*Phleum pratense*	0.0002						

includes a large amount of inorganic matter. Allergens from up to 20 sources including molds, tree, weed and grass pollens and animal dander were detected in paved road dust samples. The most abundant allergens found in the paved road dust samples were Cladosporium mold, sycamore, Russian thistle, lamb's quarters and mountain cedar. Variation of allergen potency with season was small, typically falling within a factor of 2 at a sample site. Likewise, the variation among sampling sites was relatively small.

Allergenic activity of paved road dust and atmospheric particulate matter. Slot blots of the extracts from environmental samples and from pure allergen source material samples were probed with pooled atopic human sera to determine the relative allergenicity, using total IgE binding as an endpoint. This direct method provides a semi-quantitative measure of total IgE binding to allergens and differs from the inhibition-immunoassay employed above which allows for the discrimination of distinct allergen sources. A comparison of the relative allergenicity of ambient airborne particles, size-fractionated paved road dust and pure allergen source material is presented in Figure 2. Twenty-six pure allergen sources were tested with the atopic serum pool. All except one were detected, indicating the presence of allergen-specific IgE for each of the 25 source materials shown in Figure 2 in the atopic patient blood serum pool. The Cladosporium mold source material extract test (not shown) did not blot well, but dose response curves developed by serial dilution of all other control allergen extracts were linear over a range of 1.5 orders of magnitude. Negative controls, in which extracts of

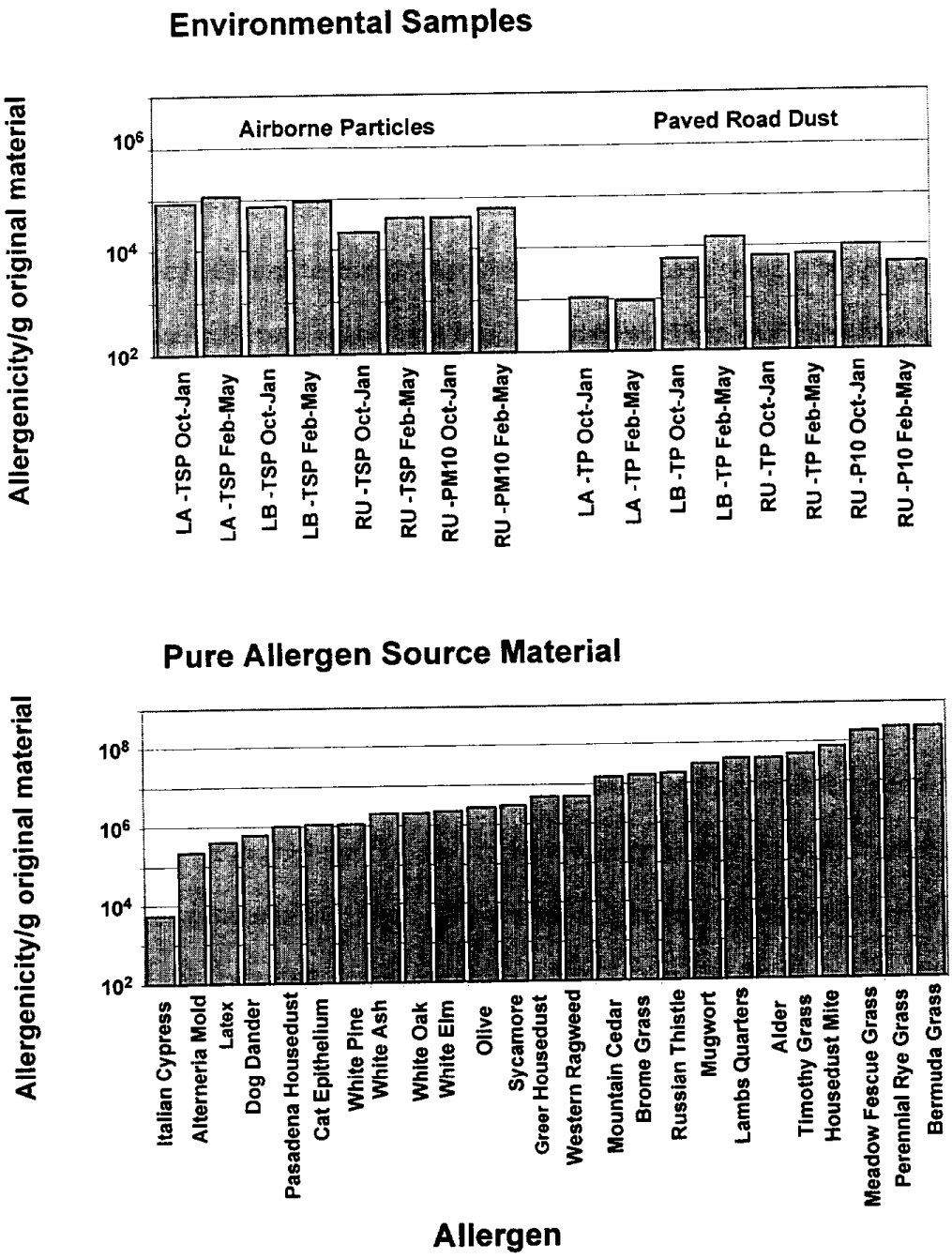

Figure 2. Relative Allergenicity of Ambient Airborne Particles and Size - Fractionated Paved Road Dust Source Samples Compared to Pure Allergen Source Material.

Extracts of environmental or authentic allergen source material samples were probed with pooled atopic human sera to allow binding of IgE for the determination of relative allergenicity according to the slot blot procedure described in Methods. Environmental sample information includes 3 locations - Los Angeles (LA), Long Beach (LB) and Rubidoux (RU); 2 temporal composites - Oct 95-Jan 96 and Feb 96-May 96; and 2 particle size fractions - TSP and PM_{10}.

environmental allergen source materials were probed with a pool of human IgE stripped sera, were blank. The airborne particles were more allergenic per unit mass extracted than the paved road dust. When compared on the basis of mass of raw particles that had to be processed to achieve a particular optical density in the slot blot system, the allergenic potency of the airborne particles was 100 fold higher for the Los Angeles site and 10 fold higher for the Long Beach and Rubidoux locations than what was found with the resuspended paved road dust source samples. The allergenic potency of airborne particulate matter was greater for the urban Los Angeles and Long Beach sites than for the Rubidoux site (Figure 2). Seasonal variation in allergenicity was evident for airborne particulate matter samples, showing higher values for the February through May period than for the October through January period. No seasonal trend was apparent for the allergenic potency of the paved road dust samples. At the Rubidoux sampling site, where airborne particles in two different size ranges were sampled, allergenic potency per unit particulate mass extracted was higher for the PM_{10} particulate matter samples than for the TSP samples. A comparison of the airborne particulate samples with the pure allergen source material samples shows that house dust, tree pollens, weed pollens and grass pollens are more potent than airborne TSP. The Greer house dust, a commercially available composite source from homes containing no furry animals, was 5 times more potent than the Pasadena house dust, a sample from a home with a cat. The Pasadena house dust, dog dander and cat dander showed comparable IgE-binding capacities, a result consistent with a large contribution for animal dander to this house dust allergenicity, where as the high amount of IgE bound by the Greer

sample would point to a role for more potent allergen source material, such as weeds, house dust mite, grasses or other sources not tested.

Paved road dust contribution to airborne particulate mass and allergen concentrations. Paved road dust contributions to airborne particulate mass concentration were estimated using the chemical composition profiles of size-fractionated TSP-equivalent paved road dust and TSP-size airborne particulate (Table 2). The chemical profiles of size-fractionated PM_{10}-equivalent paved road dust (Table 1) were used in conjunction with supplemental data, supplied by the the California Air Resources Board (CARB) and the SCAQMD for PM_{10} airborne particulate matter composition at Rubidoux. The supplemental information on airborne PM_{10} chemical composition consisted of elemental data obtained by XRF from the CARB dichotomous sampler located at Rubidoux for the time period from February through May 1996 and SCAQMD data on PM_{10} elemental composition from the PTEP data base at Rubidoux for the period October 1995 through January 1996. An upper limit estimate for the quantity of airborne particulate matter that can be attributed to paved road dust for each sampling site was computed by determining the best fit quantity of paved road dust source material needed to reproduce the Ti, Mn, and Fe concentrations in the airborne particle samples as calculated by ordinary least squares regression analysis. Previous analysis shows that the ambient concentrations of these elements in TSP samples collected in the Los Angeles area are dominated by road dust sources (Cass and McRae, 1983). The results are presented in Table 5. It is estimated that road dust contributes up to

36 to 64% of the airborne TSP at these sites, a range of values that overlaps the previous estimates of Cass and McRae, (1983). At the Rubidoux site paved road dust contributed a smaller proportion of the airborne PM_{10} particulate matter samples than for the airborne TSP samples. The relative allergenicity results presented in Figure 2 and the estimates of the paved road dust source contribution to airborne particle mass shown in Table 5 were used to estimate upper limits for the contribution of resuspended paved road dust to the allergenicity of the airborne particulate material. The results, also presented in Table 5, showed that from 0.5% to as much as 13% of the airborne particulate allergenicity was due to resuspended paved road dust, depending on the site and time period examined. While the allergenic potential was low for the the heavily industrialized central Los Angeles site, a site that lacks much vegetation, paved road dust contaminated with biological materials collected at the more urban Long Beach and Rubidoux sites contributed an order of magnitude more allergenicity to the measured airborne particulate matter. Comparison of the two particle sizes showed that paved road dust contributed less to airborne PM_{10} allergenicity than to TSP-associated allergenicity. The paved road dust values shown in Table 5 are upper limit estimates in the sense that all airborne mineral dust is attributed to paved road dust. To the extent that emissions of crustal material from other sources (e. g. unpaved roads) affect these sampling sites, the paved road dust values would be lower. These other fugitive dust sources of course would contain allergenic material resuspended by means analogous to that for paved road dust, a distinction that would require further investigation beyond the present study.

Table 5. Estimation of Paved Road Dust Contribution to Airborne Particle Mass and Allergenicity at Three Locations in the Los Angeles Basin.

Location & Particle Size (Composite period)	Analysis [a] Method	Paved Road Dust [b] Contribution to Total Airborne Particle Mass (% of weight)	Airborne Particle Concentration ($\mu g/m^3$)	Resuspended [b] Paved Road Dust Concentration ($\mu g/m^3$)	Estimated Paved Road Dust Contribution to Total Airborne Allergenicity (%)
Los Angeles -TSP					
Oct - Jan	ICP -MS	42.9	110.7	47.5	0.5
Feb - May	ICP -MS	55.8	60.7	33.9	0.5
Long Beach - TSP					
Oct - Jan	ICP -MS	51.3	95.3	48.9	4.6
Feb - May	ICP -MS	63.8	51.6	32.9	11.3
Rubidoux - TSP					
Oct - Jan	ICP -MS	43.2	133.7	57.8	13.3
Feb - May	ICP -MS	35.5	85.7	30.4	6.1
Rubidoux - PM_{10}					
Oct - Jan	XRF	33.3	93.0	31.0	8.0
Feb - May	XRF	26.4	56.5	14.9	2.1

[a] Trace elements used for the receptor modeling were determined either by Inductively coupled mass spectrometry (ICP-MS) or X-ray fluorescence (XRF). [b] Ti, Mn and Fe were used as tracers for paved road dust in the receptor modeling to calculate an upper limit for the contribution of paved road dust to airborne particle mass.

DISCUSSION

The results presented here clearly demonstrate that paved road dust and airborne ambient particulate matter contain biologic materials that may cause or exacerbate allergenic disease in humans. The results also clearly demonstrate that paved road dust can be found in significant quantities in ambient particulate matter samples taken at several sites in the Los Angeles Basin of California. The particle size distributions for the size-fractionated paved road dust source samples from Los Angeles, Long Beach and Rubidoux (Fig. 1) demonstrate the presence of respirable particles (<10 μm), capable of entering the respiratory tract, as well as fine particles (<2 μm), capable of penetrating deep into the alveolar region of the lung. Exposure of the nasal pharangeal mucosa to the larger particles could result in hay fever symptoms such as runny nose, watery eyes and sneezing, while exposure of the bronchial and alveolar regions to smaller particles could result in swelling of lung tissue and asthma. The mass particle size distributions for paved road dust presented here are consistent with those of Chow and colleagues (1994) and are comparable to the mass size distributions for the airborne particulate matter for various locations in the Los Angeles basin, with the PM_{10} and PM_2 airborne particle fractions contributing 55 to 65 % and 6 to 7% of the total suspended particulate matter, respectively (South Coast Air Management District Data Base, 1993; Hannigan et al., 1996).

Although the elemental composition of airborne particulate matter and paved road dust has been routinely characterized in the past, one of the main objectives of

the present study was to measure and characterize the allergenic potential of the biological components, represented by the amount of extractable protein, in airborne particulate matter and paved road dust. Results show that the size-fractionated paved road dust and the airborne particulate matter samples from Los Angeles, Long Beach and Rubidoux all contained protein. However, the protein yields per gram of source material from the airborne particulate matter were an order of magnitude higher than those from the size-fractionated paved road dust samples. This suggests that a significant amount of airborne protein must come from sources of particulate matter with much higher protein contents than paved road dust – perhaps "pure biological" sources. Furthermore, the fact that the protein yield was higher for the PM_{10} particle size than for the TSP particle size for both paved road dust and for airborne particulate matter suggests the presence of biological material fragments smaller than intact pollen grains. The low protein content of the paved road dust collected at the central Los Angeles site is an interesting finding. Its low protein content is most likely due to its industrial location, which has less local vegetation than the more residential Long Beach and Rubidoux sites. The Los Angeles airborne particulate matter protein yields, however, were comparable to those of Long Beach and Rubidoux, showing that the low protein yields for the local paved road dust at Los Angeles had little effect on the amount of airborne protein. The temporal variation in protein yield per gram of processed airborne particulates, showing a peak in the months of November, December and January, is not reflected by the local pollen grain and mold spore counts. Pollen counts are higher in the spring months. Mold counts, which fluctuate somewhat on a

daily basis, are typically stable when compared on a monthly basis (Aeroallergen Monitoring Network, 1995). The likely explanation for the increased protein yield during the November through January period is the decreased winter-time atmospheric mixing, which could lead to less dilution of the non-pollen "pure biological" source of protein identified above. There are large emissions to the atmosphere from man-caused sources of non-fossil carbon in Los Angeles (Hildemann et al.,1994) including the emissions from food cooking and wood combustion. Biomolecules such as cholesterol escape from these sources (Rogge et al., 1991) and it is possible that proteins are released as well.

Only a small portion of the proteins from each allergen-containing pure source material are allergenic. About 0.5 to 1% of the total proteins from each source, consisting of a few dozen proteins, may be allergenic and in general only 2 to 4 of the proteins from a single source are major allergens (Guerin, 1993), capable of eliciting a strong response because of their high quantity or the presence of strong IgE-binding epitopes. The source-specific allergens detected in the TSP-equivalent size-fractionated paved road dust samples (Table 4) indicate that allergens from a large variety of sources are associated with these sedimented particles. The high content of *Cladosporium herbarum* mold allergen is consistent with its high abundance in nature as a decay fungus. Based on airborne spore counts in Los Angeles *Cladosporium* is also the most common spore type (Aeroallergen Monitoring Network, 1995). The two weeds, Russian thistle and lambs quarters, stand out as allergen sources throughout the whole sampling period. However, airborne pollen counts indicate pollination primarily in August

through October (Aeroallergen Monitoring Network, 1995). A combination of three alternative explanations could contribute to this extended period of allergen activity. First, allergens may come from nonpollen plant parts such as stems and leaves as found for mountain cedar (Goetz et al., 1995) and the grass *Dactylis glomerata* (D'Amato et al., 1991). The allergenic proteins could be quite stable and persist in the environment over an extended period (Moneret-Vautrin et al., 1997). Thirdly, some closely related plant proteins from other types of plants may, contain the same IgE-binding epitope(s) – the region of the protein to which the specific antibody binds. This could be responsible for cross reactivity (Fuchs et al. 1997; Hoffmann et al 1997). For instance, even plants from different genera such as mugwort, ragweed, Timothy grass and natural rubber latex have been shown to share IgE epitopes (Fuchs et al., 1997). From the standpoint of allergic disease, the consequence of cross reactivity is sensitization to the entire group of cross-reacting allergens, without prior exposure to any more than one member of the group. In the end, it is the allergen and not its origin that is of importance and nonpollen plant debris or cross-reacting material could be significant from a health perspective.

No natural rubber latex allergens were detected in the paved road dust source samples. In an earlier study, however, natural rubber latex allergens were detected in ambient particulate material deposited on a guardrail adjacent to a curve on a freeway interchange as well as in airborne particulate material (Miguel et al., 1996). These potentially conflicting results could be explained by differences in driving conditions and sampling locations for the roadways examined in each of the two studies. Previous observations show increased tire wear particles from high-

cornering wear on curves at a speed of 40 miles per hour (Pierson et al., 1974). In fact, the guardrail material contained about 75 % rubber particles whereas no rubber particles were observed upon examination by light microscopy of the paved road dust collected here from the center two thirds of straight sections of city surface streets.

Several recent epidemiological studies have pointed out a relationship between vehicular traffic and respiratory disease. A study in Birmingham UK showed that children with diagnosed asthma admitted to a hospital were more likely to live in an area with high traffic flow located within 500 m from a main road than children admitted for nonrespiratory reasons or children chosen at random from the community (Edwards et al, 1994). In a south Holland study, cough, wheeze, runny nose and diagnosed asthma were significantly more often reported for children living within 100 m from the freeway (van Vleit et al, 1997). In the Nikko-Imaichi district of Japan, the prevalence of Japanese cedar pollinosis was higher among residents along the innercity road lined with cedar trees, and having heavy automobile traffic, than among residents in the city or nearby cedar forests with less automobile traffic (Ishizaki et al, 1987). The main question remains, what product or process from traffic could be responsible for the observed symptoms? Motor vehicle emissions, including automobile and diesel truck exhaust were suggested as candidates in the studies above. The current study has suggested a role for paved road dust.

Results presented in this study and in agreement with those of others (Cass and McRae, 1983; Watson et al.,1994; Chow et al., 1990) indicate that suspended

paved road dust is a major contributor to airborne particulate matter in Los Angeles and other cities. This fact, together with the detection of allergens in the paved road dust samples leads us to conclude that there is some increase in airborne allergen concentration due to resuspension of the allergen-containing paved road dust by passing traffic. Such a process could play a significant role in the presence of dense pollen or plant debris or cedar cross-reactive source material (e.g. tire dust) (Miguel et al., 1996) such as in the Japanese cedar pollinosis study which showed a strong relationship between health effects and traffic flow. Results for spot checks at three sites in the Los Angeles area show that up to 13% of the airborne allergenicity can be attributed to paved road dust emissions, although results do vary from site to site depending on the quantity of surrounding vegetation present.

Los Angeles is not heavily vegetated by comparison to many other cities. In light of this the process we have described here could convey much larger quantities of allergens in other locations. We conclude that paved road dust is the outdoor analog of house dust, a ubiquitous mixture of allergenic material resuspended into the atmosphere by passing traffic and to which virtually the entire population is exposed. While some individuals may be exposed to more paved road dust than others, because of their residential location, the allergenic potential of the paved road dust and the relative sensitivity of individuals inhaling particulate air pollution containing paved road dust could explain, in part, some of the health effects seen with ambient particulate matter exposure.

REFERENCES

1. Air Resources Board. California emissions trends 1975 – 2010. California Environmental Protection Agency (1993).

2. Aeroallergen Monitoring Network Pollen and Spore Report 1994, Milwaukee:American Academy of Allergy, Asthma and Immunology (1995).

3. Berg J, Røyset O, Steinnes E. Blank values of trace elements in aerosol filters determined by ICP-MS. Atmos Environ 27A:2435-39 (1993).

4. Birch ME, Cary RA. Elemental carbon based-method for monitoring occupational exposures to particle diesel exhaust. Aerosol Sci Technol 25:221-41 (1996).

5. Busse WW, Reed CE, Hoehne JH. Where is the allergenic reaction in ragweed asthma? II. Demonstration of ragweed antigen in airborne particles smaller than pollen. J Allergy Clin Immunol 50:289-92 (1972).

6. Cass GR, McRae GJ. Source-receptor reconciliation of routine air monitoring data for trace metals: an emission inventory assisted approach. Environ Sci Technol 17:129-39 (1983).

7. Chow JA, Watson JG, Egami RT, Frazier CA, Lu Z, Goodrich A, Bird A. Evaluation of regenerative-air vacuum street sweeping on geological contributions to PM_{10}. J Air Waste Manage Assoc 40:1134-24 (1990).

8. Chow JC, Watson JG, Houck JE, Prichett LC, Rogers CF, Frazier CA, Egami RT, Ball BM. A laboratory resuspension chamber to measure fugitive dust size distributions and chemical compositions. Atmospheric Env 28:3463-81 (1994).

9. D'Amato G, De Palma R, Verga A, Martucci P, Liccardi G, Lobefalo G. Antigenic activity of nonpollen parts (leaves and stems) of allergenic plants (*Parietaria judiaca* and *Dactylis glomerata*). Annals of Allergy 67:421-24 (1991).

10. Dockery DW, Pope CA III. Acute respiratory effects of particulate air pollution. Ann Rev Public Health 15:107-32 (1994).

11. Dzubay TG. X-ray Analysis of Environmental Samples. Ann Arbor, MI: Ann Arbor Science, (1977).

12. Edwards J, Walters S, Griffiths RK. Hospital admissions for asthma in preschool children: relationship to major roads in Birmingham, United Kingdom. Archives of Environmental Health 49:223-7 (1994).

13. Fuchs T, Spitzauer S, Vente C, Hevler J, Kapiotis S, Rumpold H, Kraft D, Valenta R. Natural latex, grass pollen and weed pollen share IgE epitopes. J Allergy Clin Immunol 100:356-64 (1997).

14. Goetz DW, Goetz MA, Whisman BA. Mountain cedar allergens found in nonpollen tree parts. Annals of Allergy, Asthma & Immunology 75:256-60 (1995).

15. Gray HA, Cass GR, Huntzicker JJ, Heyerdahl EK, Rau JA. Characteristics of atmospheric organic and elemental carbon particle concentrations in Los Angeles. Environ Sci Technol 20:1567-82 (1986).

16. Guerin B. Pollen et Allergies. Varennes-en-Argonne:Allerbio, 1993.

17. Hannigan MP, Cass GR, Lafleur AL, Basby WF, Thilly WG. Seasonal and spatial variation of the bacterial mutagenicity of fine organic aerosol in southern California. Environ Health Persp 104:428-36 (1996).

18. Hildemann LM, Klinedinst DB, Klouda GA, Currie LA, Cass GR. Sources of urban contemporary carbon aerosol. Environ Sci Technol 28:1565-76 (1994).

19. Hoffmann A, Jamin A, May S, Haustein S, Vieths S. A new in vitro model for testing of food allergens: Allergen-specific mediator release of passively sensitized rat basophil leukemia cells. Food and Agricultural Immunology 9:309-25 (1997).

20. Ishizaki T, Koizumi K, Ikemori R, Ishyama Y, Kushibiki E. Studies of prevalence of Japanese cedar pollinosis among the residents in a densely cultivated area. Annals of Allergy 58:265-70 (1987).

21. John W, Reischl G. A cyclone for size selective sampling of ambient air. JAPCA 30:872-76 (1980).

22. Knox RB. Grass pollen, thunderstorms and asthma. Clin Exp Allergy 23:354-59 (1993).

23. Miguel AG, Cass GR, Weiss J, Glovsky MM. Latex allergens in tire dust and airborne particles. Environ Health Perspectives 104:1180-86 (1996).

24. Monret-Vautrin DA, Kanny G, Rancé F, Lemerdy Ph. Les allergènes végétaux alimentaires. Allergies associées et réactions croisées. Rev fr Allergol 37:316-24 (1997).

25. Mueller PK, Mendoza BV, Collins JC, Wilgus EA. Application of ion chromatography to the analysis of anions extracted from airborne particulate matter. In: Ion chromatographic analysis of environmental pollutants (Sawicki E, Mulik JD, Wittgenstein E, eds). Ann Arbor, MI: Ann Arbor Science. 1978; 77-86.

26. Owen MK, Ensor DS, Sparks LE. Airborne particle sizes and sources found in indoor air. Atmos Environ 26:2149-62 (1992).

27. Pierson WR, Brachaczek WW. Airborne particulate debris from rubber tires. Rubber Chem Technol 47:1275-99 (1974).

28. Pope AM, Patterson R, Burge H (eds.) Indoor allergens: assessing and controlling adverse health effects. Washington DC: National Academy Press. 1993.

29. Rogge WF, Hildemann LM, Mazurek MA, Cass GR, Simoneit BRT. Sources of fine organic aerosol. 1. Charbroilers and meat cooking operations. Environ Sci Technol 25:1112-25 (1991).

30. Rogge WF, Hildemann LM, Mazurek MA, Cass GR, Simoneit BRT. Sources of fine organic aerosol. 3. Road dust, tire debris, and organo-metallic brake lining dust: roads as sources and sinks. Environ Sci Technol 27:1892-1904 (1993).

31. Schauer JJ, Rogge WF, Hildemann LM, Mazurek MA, Cass GR. Source apportionment of airborne particulate matter using organic compounds as tracers. Atmos Environ 30:3837-55 (1996).

32. Solomon PA, Fall T, Salmon L, Cass GR, Gray HA. Davidson A. Chemical characteristics of PM_{10} aerosols collected in the Los Angeles area. JAPCA 39:154-63 (1989).

33. Solórzano L. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol Oceanogr 14:799-801 (1969).

34. South Coast Air Quality Management District Data Base (1993).

35. Stoscheck CM. Quantitation of protein. In: Methods in enzymology, vol 182 (Deutscher MP, ed.) New York:Academic Press, 1990; 50-68.

36. Van Vliet P, Knape M, Hartog J, Janssen N, Harssema H, Brunekreff B. Motor vehicle exhaust and chronic respiratory symptoms in children living near freeways. Environmental Res. 74:122-32 (1997).

37. Watson JG, Chow JC, Lu Z, Fujita EM, Lowenthal DH, Lawson DR, Ashbaugh LL. Chemical mass balance source apportionment of PM10 during the Southern California Air Quality Study. Aerosol Sci Technol 21:1-36 (1994).

For more information about the ARB's Research Division, its research and activities, please visit our Web site:

http://www.arb.ca.gov/rd/rd.htm